Assessment of stroke drivers' performance in a driving simulator: A pilot study results

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Abstract

About 795,000 people experience a new or recurrent stroke in the United States each year and it is known that between 30% and 43% of the stroke survivors in the US resume driving within one year of the stroke incidence. In Korea, the stroke is the second leading cause of death and the incidence of stroke onset increases steadily. However, there are no guidelines for assessing driving performance for stroke patients yet. In this study, we developed an assessment environment using a driving simulator to evaluate driving performancce of stroke patients. The driving scenario consists of 3.5km urban traffic conditions (3 minutes), 10km divided 4-lane straight highway (6 minutes), and 7km 2-lane curved or hilly rural roads (6 minutes). Performance parameters during the simulated drive were automatically generated by the simulator software. The parameters included number of road edge excursions, centerline crossings, collisions, reaction time, and runtime. The stroke drivers' performace was compared with healthy young drivers.

Keywords: Driver Rehabilitation, Stroke Patients, Stroke Driver Performance, Driving Simulator

Introduction

In Korea, the stroke is the second leading cause of death and the incidence of stroke onset increases steadily. Each year, about 105,000 Korean people experience a new or recurrent stroke. On average, every 5 minutes stroke attacks someone in Korea [1]. For those persons with disability, driving is an important activity of daily living and an integral part of mobility and independence that affects physical, social, and economic well being.

However, the ability to drive is often affected by various motor, visual, cognitive, perceptual and sensory deficits commonly experienced after stroke. Therefore there are limits and restrictions on safety driving [2]. Unfortunately, there is no guideline for assessing driving performance for stroke patients in South Korea.

Thus, the purpose of this study was to develop a driving simulator-based assessment platform for evaluating the driving ability of stroke and to validate the methodology by comparing their driving performance with healthy younger drivers.

Methods

Participants

To conduct a pilot study using a driving simulator, 18 subjects, 9 healthy young adults and 9 patients with stroke, were participated. The stroke patients were recruited from the Kang Hospital at Daegu, South Korea. All participants had a mild stroke, drove before stroke, drove on average more than 3 years and scored 24 points or greater on the mini mental status exam.

The simulator-based driving performance of the stroke drivers was compared with 9 healthy younger drivers. The subjects with stroke and healthy drivers have not previously participated in a simulated driving study.

Apparatus

The experiment was conducted in a fixed-based driving simulator, which incorporated STISIM Drive™ software and a fixed car cab (see Figure 1). Graphical updates to the virtual environment were computed using STISIM Drive™ based upon inputs recorded from the accelerator, brake and steering wheel with tactile force feedback. The virtual roadway was displayed on a wall-mounted screen at a resolution of 1024 x 768.

Figure 1. The DGIST fixed-base driving simulator

Oh, H., Son, J., Lee, J., Park, M., and Shin, H., "Assessment of stroke drivers' performance in a driving simulator: A pilot study results", The Japanese Journal of Ergonomics, Vol. 49., pp. 512-515, 2013.

Sensory feedback to the driver was also provided through auditory and kinetic channels. Distance, speed, steering, throttle, and braking inputs were captured at a nominal sampling rate of 30 Hz [3].

Procedure

As shown in Figure 2, following informed consent and completion of a pre-experimental questionnaire, the participants received 5 minutes of driving experience and adaptation time in the simulator. In a main experiment session, the patients drove on the urban, highway and rural traffic condition in a session.

As shown in Figure 3, the driving scenario consists of 3.5km urban traffic conditions (3 minutes), 10km straight highway with divided 4 lanes (6 minutes) and 7km 2-lane curved and hilly rural roads (6 minutes) (see Figure 3).

Dependent variables

Performance parameters during the simulated driving were collected through the simulator software. The parameters included runtime, mean speed, collisions and number of road edge excursions and centerline crossings, which calculated from every road condition. The reaction time was calculated using time-to-brake from the start time of a sudden back-up car event on an urban road. The parked vehicle was triggered by the simulated vehicle location based on 4 seconds of Time-to-Collision (TTC).

Data Analysis

Statistical comparisons of the driving performance between stroke and healthy subjects were analyzed using a paired t-test on the SPSS version 17. In all cases, ($p < 0.05$) was taken as the level of significance.

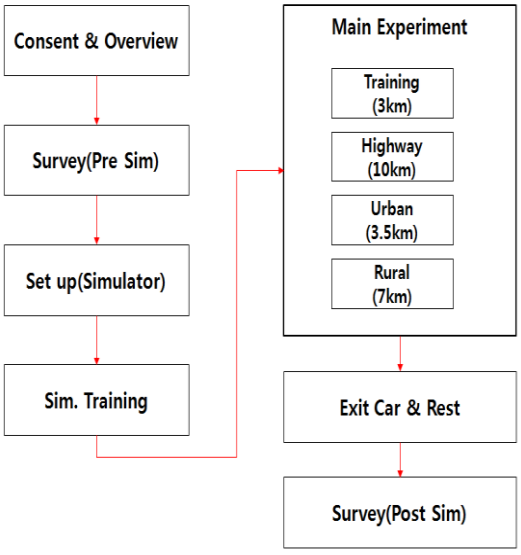
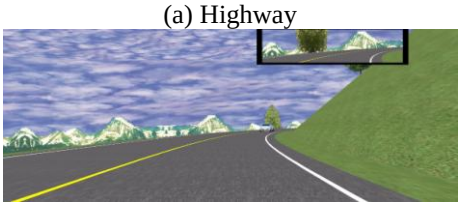
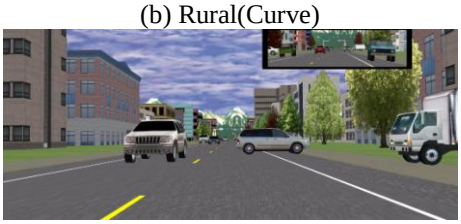


Figure 2. Structure of experimental protocol

(a) Highway



(b) Rural(Curve)



(c) Urban

Figure 3. Road scenarios: Highway, Rural and Urban

Results

Runtime and Average speed

Based on the scenario sections, i.e., urban, highway and rural, each driver's runtime and average speed described in Table 1. In the runtime and average speed parameters, the stroke participants were slower and drove longer time than their healthy cohorts. The significance appeared in urban and rural scenarios ($p<.05$).

Table 1. Runtime and average speed on scenario

	Urban		Highway		Rural	
Stroke	**Runtime**	**Average speed**	**Runtime**	**Average speed**	**Runtime**	**Average speed**
S01	234.3	55.5	233.1	94.1	329.2	71.2
S02	286.7	45.1	262.8	96.0	355.0	66.0
S03	227.2	55.5	247.0	88.8	350.6	66.8
S04	280.4	44.9	275.3	79.7	411.4	58.0
S05	321.6	39.2	280.6	89.9	466.8	50.3
S06	261.1	49.6	247.2	88.8	413.5	56.7
S07	339.8	37.1	293.2	86.1	310.2	75.5
S08	376.2	33.5	256.2	85.6	366.3	64.1
S09	467.2	27.1	345.0	73.2	613.9	38.2
Avg	**310.5***	**43.1***	271.1	86.9	**401.9***	**60.8***
SD	76.2	9.7	33.4	7.0	93.0	11.4
Healthy	**Runtime**	**Average speed**	**Runtime**	**Average speed**	**Runtime**	**Average speed**
H01	216.1	58.3	252.3	86.9	299.7	78.1
H02	250.2	50.4	273.8	92.2	331.2	70.8
H03	230.9	54.6	200.6	109.3	264.6	88.4
H04	212.5	61.3	294.4	85.7	259.1	90.3
H05	216.1	58.3	252.3	86.9	299.7	78.1
H06	250.2	50.4	273.8	92.2	331.2	70.8
H07	230.9	54.6	200.6	109.3	264.6	88.4
H08	225.2	55.9	234.1	93.7	288.6	81.1
H09	232.7	54.1	265.9	94.9	321.7	72.8
Avg	**229.4***	**55.3***	249.8	94.6	**295.6***	**79.9***
SD	13.8	3.6	32.6	9.0	28.6	7.7

* Significance between stroke and healthy group at $p<.05$

In the urban and rural scenario, the stroke group showed higher standard deviation of runtime and speed with than that with healthy group. It means the stroke group had difficulties in speed control.

Line crossing, Collision, and Reaction time

The number of line crossing, collision and reaction time were considered as indicators for assessing the driving ability. In the line crossing indicator, 4 out of 9 stroke patients and 2 out of 9 healthy drivers crossed the centerline more than once on the urban road (see Table2). On the highway, 3 stroke patients crossed a road edge more than once, but no healthy drivers crossed. On the rural road, 7 stroke patients and 7 healthy subjects crossed a road edge more than once. Especially, one subject with stroke crossed a centerline and a road edge and centerline 19 times.

Regarding the indicator of accident, the collision occurs from 3 subjects with stroke on the unban road (S01, S02, S06) and 1 subject with stroke on the rural road (S4). In the healthy group, there was only one collision from one subject on the urban road.

For the reaction time, there was no significant difference between stroke and healthy group ($p>.05$). In general, the reaction time was longer than 3 seconds; the subjects (S01, S06) were involved in an accident at the car-backup event scenario.

Discussion

The purpose of this study was to assess the driving ability of stroke using driving simulator and compare their driving performance with healthy young drivers. In runtime and average speed parameters, the stroke group showed a lower speed and longer runtime compared with healthy subjects.

In case of line crossing parameter, the centerline crossing and road edge excursion were considered. The line crossing was found from healthy group as well as stroke, because there was no instruction to prohibit from line crossing in this study. In the main study, we need to focus on adding more parameter about lateral driving performance such as SDLP (Standard deviation of Lane Position) and SRR (Steering wheel reversal rate) [4], to assess lane keeping ability of stroke patients with hemiplegia.

The collision occurred from 4 subjects in stroke group and 1 subject in healthy group at every scenario. Since the collision is directly associated with life and safe driving, further information such as control of steering wheel, braking, acceleration need to be analyzed in the event of collision.

Statistically, there was no difference between stroke and healthy group in reaction time. Further study should be considered on adding more sophisticated reaction time calculation methods such as time to release from an accelerator and time to step on a brake in unexpected situations.

Another limitation of this study is the age differences were not taken into account. Thus, additional experiments need to be conducted with counter-balanced age groups.

Acknowledgement

This research was supported in part by Daegu Gyeongbuk Institute of Science and Technology (DGIST) Research Program of the Ministry of Science, ICT and Future Planning (MSIP) (Project No. 13-S-01), and Establishment Program of Industrial Original Technological Base of the Ministry of Trade, Industry and Energy (MOTIE) (Project No. M0000009).

Table 2. Line crossing (shoulder & center), accident, reaction time on scenario

	Urban				Highway			Rural			Total		
Stroke	**Line Crossing (Shoulder)**	**Line Crossing (Center)**	**Accident**	**Reaction time**	**Line Crossing (Shoulder)**	**Line Crossing (Center)**	**Accident**	**Line Crossing (Shoulder)**	**Line Crossing (Center)**	**Accident**	**Line Crossing (Shoulder)**	**Line Crossing (Center)**	**Accident**
S01	0	0	1	3.1	0	0	0	0	1	0	0	1	1
S02	0	0	1	2.1	0	0	0	0	1	0	0	1	1
S03	0	0	0	1.9	0	0	0	0	1	0	0	1	0
S04	0	0	0	2.2	7	0	0	9	3	1	16	3	1
S05	0	0	0	2.4	0	0	0	0	0	0	0	0	0
S06	0	1	1	3.9	1	0	0	0	0	0	1	1	1
S07	0	2	0	1.5	0	0	0	0	1	0	0	3	0
S08	0	1	0	1.5	0	0	0	0	1	0	0	2	0
S09	0	1	0	1.5	2	0	0	0	2	0	2	3	0
Healthy	**Line Crossing (Shoulder)**	**Line Crossing (Center)**	**Accident**	**Reaction Time**	**Line Crossing (Shoulder)**	**Line Crossing (Center)**	**Accident**	**Line Crossing (Shoulder)**	**Line Crossing (Center)**	**Accident**	**Line Crossing (Shoulder)**	**Line Crossing (Center)**	**Accident**
H01	0	2	0	2.2	0	0	0	0	1	0	0	3	0
H02	0	0	0	2.4	0	0	0	0	0	0	0	0	0
H03	0	0	0	1.9	0	0	0	0	2	0	0	2	0
H04	0	0	1	2.2	0	0	0	0	1	0	0	1	1
H05	0	2	0	2.2	0	0	0	0	1	0	0	3	0
H06	0	0	0	2.4	0	0	0	0	0	0	0	0	0
H07	0	0	0	1.9	0	0	0	0	2	0	0	2	0
H08	0	0	0	1.9	0	0	0	0	1	0	0	1	0
H09	0	0	0	2.2	0	0	0	0	1	0	0	1	0

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